Parametric Powered-Lift Navier–Stokes Computations

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The goal of this work is to enable the computation of large numbers of unsteady high-fidelity flow simulations for a YAV-8B Harrier aircraft in ground effect by improving the solution process and taking advantage of NASA parallel supercomputers. The YAV-8B Harrier aircraft can take off and land vertically, or utilize short runways by directing its four exhaust nozzles toward the ground. Transition to forward flight is achieved by rotating these nozzles into a horizontal position.

The success and unique capabilities of the Harrier have prompted the design of a powered-lift version of the Joint Strike Fighter (JSF). Directing the exhaust nozzles toward the ground results in very complex and time-dependent flows consisting of ground vortices, jet flows along the ground plane, and hot jet fountains that impact the underside of the vehicle. The high-speed jet flows cause low pressures underneath the vehicle, resulting in loss of lift (suck-down effect). Moreover, hot gas ingestion (HGI) by the inlets can result in a sudden reduction in thrust (powered lift).

Safe flight operations near the ground are dependent on understanding and avoiding these problematic conditions. Time-accurate Reynolds-averaged Navier–Stokes (RANS) computations to date have focused on simplified geometries such as single or multiple jets in cross flow, delta wings with jets in ground effect, and a single Harrier RANS solution in ground effect. Two key obstacles remain in simulating these flows, the need for improved accuracy and the need for faster solution methods. This research focuses on faster solution methods, a key requirement for improving solution accuracy and enabling flow simulations for powered-lift vehicles in ground effect in a more routine manner.

Forty-five time-accurate RANS flow simulations using the OVERFLOW-MLP code have been computed with a free-steam velocity V = 33 knots, an angle of attack range of 4–12 degrees with 1-degree increments, a height range of 10–30 feet with 5-foot increments, and a Reynolds number based on the body length of Re = 15.2 million. Because of the danger of gas injection and the suck-down effect, a Harrier pilot will not ordinarily maintain a constant altitude of less than 30 feet when operating at very low speeds or hover flight conditions. However, typical aerodynamic models require the static stability derivatives, or forces and moments, near the ground to simulate takeoff and landing scenarios. Therefore static computations have been carried out in this height range.

PERL scripts have been developed to automate the grid generation, numerical flow simulation, and data analysis processes. A Unix-based directory structure is used to store the thousands of files (over a terabyte) generated by these solutions. The user simply specifies the flow parameters, and the scripts automatically store and retrieve the data files. The current 45-solution database was generated using a NASA 512 processor 400-megahertz/R12000 Silicon Graphics Origin 2000 single-image computer. A typical flow simulation consisted of running nine cases concurrently using 16 processors per case, for a total of 144 processors. The number of cases and processors is arbitrary, depending on the computational resources. A nine-case run typically requires 14,000 node-hours.

Figure 1 shows two snapshots from a streak-line animation when the Harrier is 30 feet above the ground. The flow particles are colored by temperature, where red is hot and blue is cool. The ground vortex was found to vary in size with a frequency of 0.478 Hertz. Experimental measurements for a jet in crossflow found similar low frequencies. These very low frequencies require several seconds of real-time flow simulations. At this height, the inlet does not ingest any hot gasses. Figure 2 is a snapshot from a streak-line animation when the Harrier is only 10 feet above the ground. The ground vortex and its core are identified in the figure. The flow particles are rendered by small spheres and colored by temperature. The jet fountain forms a second vortex in front of the ground vortex, which is ingested by the inlet. Thus, HGI is a problem at this height. The long-term goal is to use this new capability, together with neural networks, to generate a stability and control database for a powered-lift vehicle in ground effect.

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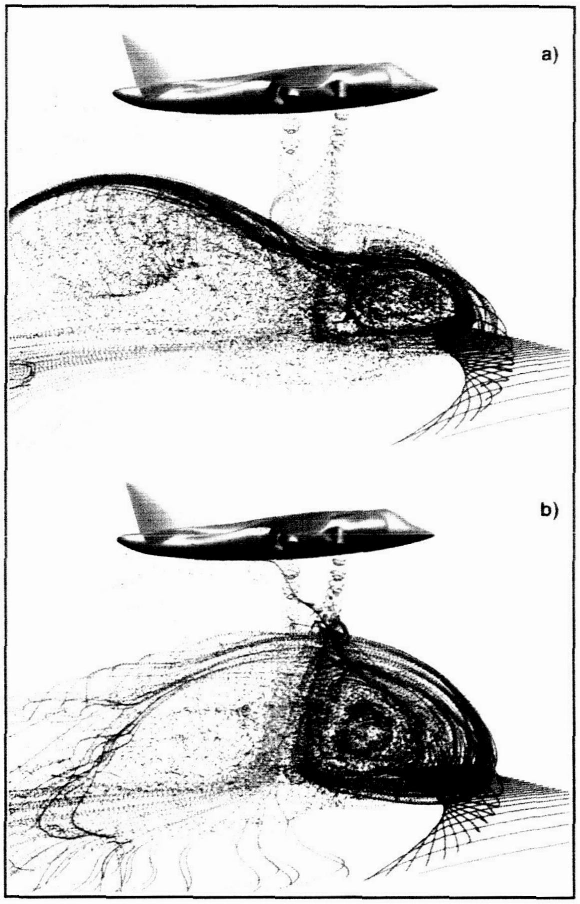

Fig. 1. Streak-line animation showing time variation of ground vortex size: height = 30 feet.

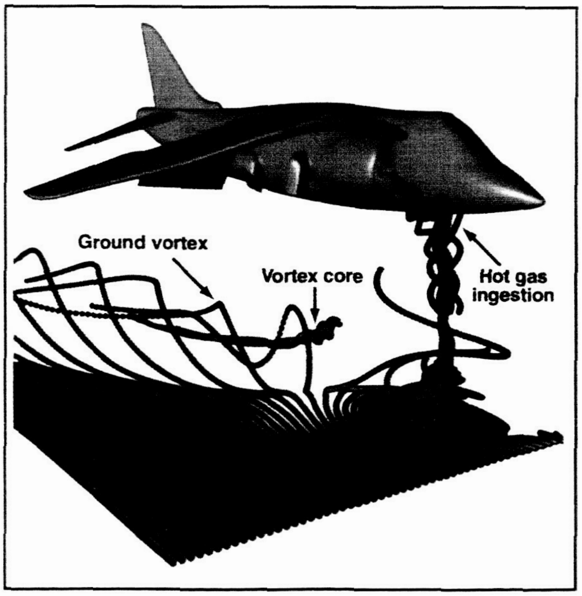

Fig. 2. Streak-line animation showing ground vortex and hot gas ingestion: height = 10 feet.